CALIFORNIA DEPARTMENT OF CONSERVATION
DIVISION OF MINES AND GEOLOGY

FAULT EVALUATION REPORT FER-239
SURFACE FAULT RUPTURE ALONG THE HOMESTEAD VALLEY, EMERSON, AND RELATED FAULTS ASSOCIATED WITH THE M_W 7.3 28 JUNE 1992 LANDERS EARTHQUAKE

by
William A. Bryant
Associate Geologist
July 18, 1994

California Department of Conservation
Division of Mines and Geology
801 K Street
Sacramento, CA 95814

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INTRODUCTION

Traces of the Homestead Valley, Emerson, Galway Lake, Maumee (new name), Upper Johnson Valley (new name), and related faults (Figure 1) are evaluated in this Fault Evaluation Report (FER) as a result of surface fault rupture associated with the 28 June 1992 M_W 7.3 Landers earthquake (Toppozada and Wilson, 1992; Hart and others, 1993; Hauksson and others, 1993; Sieh and others, 1993). Most of these faults in the Melville Lake-Emerson Lake study area were zoned for special studies[†] in March 1988 in the Melville Lake, Emerson Lake, and Galway Lake 7.5-minute quadrangles (CDMG, 1988a, 1988b, 1988c) (Figures 2a, 2b, and 2c) as part of DMG's statewide 10-region (Mojave Desert Region) Fault Evaluation and Zoning Project as authorized by the Alquist-Priolo Earthquake Fault Zoning Act[†] of 1972 (Hart, 1992; Hart and others, 1988). Extensive surface fault rupture associated with the Landers earthquake occurred mostly within EFZ boundaries, but also occurred along poorly defined faults that transferred slip from one major fault zone to another. In addition, rupture occurred along previously unmapped faults and mapped faults that lacked well-defined geomorphic evidence of Holocene displacement. Surface fault rupture associated with the Landers earthquake requires revisions to the 1988 SSZ Maps of the Melville Lake, Emerson Lake, and Galway Lake quadrangles.

SUMMARY OF AVAILABLE DATA

The reader is referred to Manson (1986a and 1986b) for complete review and evaluation of faults in the Melville Lake, Emerson Lake, and Galway Lake quadrangles. This FER primarily will focus on revision of Special Studies Zones affected by the Landers earthquake. However, previously zoned traces of the Johnson Valley and West Johnson Valley (new name) faults in the Melville Lake and Emerson Lakes quadrangles that did not rupture in the study area were photo inspected. In addition, interpretation of USDA (1952 and 1953) and BLM (1977) aerial photographs by this writer was done along traces of the Homestead Valley, Emerson, Maumee, and Upper Johnson Valley faults in order to compare the location and geomorphic expression of these faults with the Landers fault rupture. Surface fault rupture in the Melville Lake-Emerson Lake study area is presented in Figure 3 and fault traces based on interpretation of aerial photography by this writer are presented in Figures 2c, 4a, and 4b.

[†] The name of the Act was changed on January 1, 1994 to the Alquist-Priolo Earthquake Fault Zoning Act and the name of Special Studies Zones to Earthquake Fault Zones (EFZ).

LANDERS EARTHQUAKE

A M_W 7.3 earthquake occurred at 04:57 local time on 28 June 1992 (Toppozada and Wilson, 1992; Hauksson and others, 1993). The epicenter was located near the hamlet of Landers, about 8 km north of Yucca Valley (Figures 5a and 5b). Surface fault rupture associated with the M_W 7.3 Landers earthquake occurred along the Johnson Valley, Kickapoo (Landers), Homestead Valley, Emerson, and Camp Rock faults (Figures 1 and 5b). Rupture south of the Pinto Mountain fault occurred along previously unmapped faults now named the Eureka Peak and Burnt Mountain faults (see Bryant, 1992 for evaluation of faults in the Yucca Valley North and Landers quadrangles and Treiman, 1992 for evaluation of faults in the Yucca Valley South and Joshua Tree South 7.5-minute quadrangles).

Rupture extended for approximately 85 km along a north to northwest trend from south of the town of Yucca Valley to about 32 km southeast of Barstow (Figure 5a). Fault rupture was characterized by predominantly right-lateral strike-slip displacement along previously mapped faults, although significant fault rupture occurred along several unmapped faults. Right-lateral strike-slip displacement averaged about 200 to 300 centimeters (cm) and reached a maximum of about 600 cm along the Emerson fault (located north of the Melville Lake-Emerson Lake study area). Vertical displacements often were associated with the strike-slip displacement and ranged from an average of 30 cm (both west and east sides down) to a maximum of about 200 cm (west side down) along the Emerson fault.

METHODS OF INVESTIGATION

Approximately 3 weeks were spent in the Landers area by this writer immediately following the Landers earthquake in order to map surface rupture. Field mapping by this writer and many other geologists from DMG and the U.S. Geological Survey (including A. Barrows, M. Clark, R. Greenwood, J. Hamilton, E. Hart, C. Higgins, R. Hill, P. Irvine, J. Kahle, K. Lajoie, K. Kendrick, J. Lienkaemper, J. MacMillan, J. Matti, M. Merriam, D. Morton, D. Ponti, T. Powers, C. Prentice, M. Rymer, R. Sharp, D. Schumway, J. Treiman, and C. Wills) was accomplished principally by mapping directly onto 1:6,000 scale aerial photographs taken 2 and 5 days after the earthquake (I.K. Curtis, 1992). However, many traces were mapped during the first week by plotting directly onto 1:24,000 scale topographic maps.

About 5 weeks were spent by this writer interpreting the 1:6,000 scale aerial photographs covering the FER study area. This was accomplished mainly using a binocular microscope (11x-20x magnification), augmented with stereoscopic interpretation, in order to identify and accurately plot the location and pattern of surface fault rupture. Often it was possible to identify ruptures as small as a few centimeters, depending on lighting conditions and orientation of fractures. This method of rupture mapping also was used by K. Lajoie of the U.S. Geological Survey and copies of Lajoie's photo interpretation (photo overlays) (Lajoie, 1993) were provided to this writer. Selected areas independently mapped by this writer were compared to mapping by Lajoie. Good correlation generally was achieved between the two interpretations. Interpretations of both Lajoie and this writer were then transferred to 1:24,000 scale orthophoto quadrangles using a Bausch and Lomb Zoom Transfer scope and ultimately the rupture traces were transferred to standard 7.5-minute quadrangles. Rupture traces shown in black on Figure 3 represent a compilation of interpretations by both Lajoie and this writer. The aerial photographic interpretation was then compared to and augmented with field mapping of geologists from DMG and USGS (shown in pink) and CIT (shown in purple). Several areas were field checked by Lajoie in October 1993 in order to verify the aerial photographic interpretations. Slip data shown on Figure 3 were compiled from field mapping by DMG and USGS geologists (shown in black) and Sieh and Lilje (1994) (shown in purple). It should be recognized that not all ruptures associated with the 1992 Landers earthquake may be shown on Figure 3. This is due to incomplete coverage of the 1:6,000 scale aerial photographs, especially in the relatively broad stepover areas and distal ends of ruptures.

HOMESTEAD VALLEY FAULT

Previous Mapping

The Homestead Valley fault in the Melville Lake and Emerson Lake quadrangles was zoned for Special Studies in 1988, based on the mapping of Manson (1986a and 1986b) (Figures 2a and 2b). Manson stated that the Homestead Valley fault is an active, northwest-trending right-lateral strike-slip fault that extends from near the Emerson fault (north of this FER study area) southeastward to Homestead Valley (refer to Bryant, 1992 for discussion of Landers ruptures along the southern Homestead Valley fault).

Homestead Valley Fault Rupture

Surface fault rupture associated with the Landers earthquake occurred along the entire reach of the Homestead Valley fault in the Melville Lake-Emerson Lake study area. Maximum right-lateral strike-slip displacement of 330 cm was measured at locality 1 (Figure 3). The maximum vertical displacement was 61 cm‡ in the southern part of the Melville Lake-Emerson Lake study area along the north side of Hill 3584 (locality 2, Figure 3). Vertical displacement along the Homestead Valley fault was predominantly east side down, although locally the west side was down.

Surface fault rupture is delineated by predominantly left-stepping en echelon fractures, scarps (mostly east-facing), moletracks, graben, and sidehill troughs. Principal fault rupture occurred mostly within previously established SSZ boundaries, although significant rupture occurred outside of the zone boundaries at the southern end of the study area (locality 2, Figure 2b), the area along the east flank of Hill 3093 (locality 3, Figure 2b), and in the northeastern corner of the Melville Lake quadrangle where the transfer of right-slip from the Homestead Valley fault to the Emerson fault formed a large, broad, and complex zone of ruptures (Figure 2a). The width of the Homestead Valley rupture zone ranges from less than 1 meter at locality 4 to about 1.2 km along the fault at the southern end of the study area at locality 2 (Figure 3).

Major distributive deformation occurred at the southern end of the study area along the east side of Hill 3584 (locality 2, Figure 3) and was manifested mostly as south and west dipping thrust faults along the eastern base of the hill. Complex, distributive deformation occurred up in the hill as predominantly extensional faulting with some lateral components of displacement. Sieh and others (1993) suggested that

‡ Reports of up to 1 meter of down-to-east vertical offset were reported in the vicinity of locality 43 (Figure 3). However, subsequent mapping by USGS (R. Sharp) and CIT apparently did not verify this observation.

dextral slip along the Kickapoo (Landers) fault impinged upon the Homestead Valley fault, causing the compressional deformation (Figures 1 and 5b).

Several north-trending faults with predominantly right-lateral strike-slip displacement branched from the Homestead Valley fault, transferring slip to the Emerson fault (Figure 3). The principal concentration of this step-over is near the northeastern corner of the Melville Lake quadrangle (Figure 3). However, north-trending ruptures also were mapped just north of Hill 3584. Also, a north-northeast trending rupture may connect the Homestead Valley and Maumee faults (locality 5, Figure 3). Right-lateral strike-slip along these north-trending branch faults was up to 71 cm, although displacement generally was less than 20 cm in the FER study area.

A 3.8 km long parallel branch of the Homestead Valley fault, which was not zoned in 1988, is located along the west side of a bedrock ridge in the Melville Lake quadrangle at locality 6 (Figure 3). Rupture generally was located along the base of an existing bedrock scarp. Right-lateral strike-slip displacement up to 57 cm was reported along this branch (Sieh and Lilje, 1994) (locality 7, Figure 3).

Geomorphic Expression Homestead Valley Fault

The Homestead Valley fault is a moderately to moderately well-defined fault that is delineated by dissected linear ridges and shutter ridges in bedrock, right-laterally deflected drainages and linear drainages, ponded alluvium, degraded scarps in older alluvium, and tonal lineaments in Holocene alluvium (e.g. localities 8-13, Figures 4a and 4b). Geomorphic evidence of Holocene displacement is present along the fault, but generally is somewhat vague. My air photo interpretation generally corresponds to the mapping of Manson (1986a), although differences in detail exist, probably due to hindsight provided by the Landers earthquake (Figures 2a, 2b, 4a, and 4b). Less well-defined are the branch faults that transferred slip from the Homestead Valley fault to the Emerson fault (Figures 3, 4a, and 4b). Bedrock scarps, saddles, linear drainages, truncated older alluvium, and degraded scarps in older alluvium indicate the location of some of the branch faults (localities 14-16, Figures 4a and 4b), but generally these faults are concealed by young alluvium

EMERSON FAULT

Previous Mapping

The Emerson fault in the Melville Lake-Emerson Lake study area was zoned for special studies in 1988 based on mapping by Morton and others (1980), augmented by aerial photographic interpretation and limited field mapping by Manson (1986b) (Figures 2a and 2b). Manson concluded that the Emerson fault is a right-lateral strike-slip fault that offsets Pleistocene alluvium at least 300 meters west of Galway Lake.

Emerson Fault Rupture

Maximum right-lateral strike-slip displacement (600 cm) associated with the Landers earthquake occurred along the Emerson fault north of FER study area. However, most of the Emerson fault in the Melville Lake-Emerson Lake study area did not rupture during the 1992 event.

Surface rupture along the Emerson fault in the study area occurred north of the intersection with the Maumee fault as discontinuous, generally left-stepping en echelon fractures along a well-defined sidehill bench (Figure 3). There is a very broad zone of discontinuous fractures west of the Emerson fault on both the Melville Lake and Emerson Lake quadrangles as slip was transferred from the Homestead Valley to the Emerson fault (Figure 3).

Most of the rupture traces in Figure 3 are based on interpretation of I.K. Curtis air photos by Lajoie (1993) and this writer. Slip data is sparse along the Emerson fault in the FER study area. Right-lateral strike-slip displacement of 25 cm was reported by Sieh and Lilje (1994) (locality 17, Figure 3). Displacement rapidly increases just north of the study area. For example, a relatively continuous branch fault located 150 meters west of Hill 3466 had up to 152 cm of right-slip (Sieh and Lilje, 1994) (locality 18, Figure 3).

Geomorphic Expression Emerson Fault

I mostly agreed with mapping by Morton and others (1980) and Manson (1986b), although differences in detail and location exist (Figures 2a, 2b, 4a, and 4b). The northwesternmost trace at locality 19 (Figures 2a and 4a) is delineated by a well-defined sidehill bench (identified as a hillside trench by Morton and others). This feature seems to be mislocated by Morton and others and partly rectified by Manson, though I believe that the well-defined trace is located to the west as shown on Figures 2a and 4a. Traces mapped by this writer in the vicinity of locality 20 (Figures 2b and 4b) vary considerably from that of Morton and others and Manson. I did not verify the fault mapped by Morton and others and extended by Manson in the vicinity of locality 21 (Figures 2b and 4b). I mapped a fault farther west, based on bedrock scarps, a linear ridge, saddles, and right-laterally deflected drainages. Differences in location between the well-defined traces mapped by Morton and others and this writer exist southeast of locality 22 (Figures 2b and 4b). Here a well-defined vegetation contrast in Holocene alluvium delineates the fault and provides good evidence for Holocene offset. However, there are slight differences in location. I believe the locations shown in Figure 4b are correct.

MAUMEE FAULT

Previous Mapping

The Maumee fault, called "Fault A" by Manson (1986b), was unnamed prior to the Landers event, but since has been named after the Maumee benchmark at the southern end of the fault (locality 23, Figures 2b and 3). Traces of the Maumee fault were zoned for special studies in 1988, based mainly on mapping by Morton and others (1980), augmented with mapping by Manson (Figure 2b). Manson stated that the Maumee fault ("Fault A") generally is well-defined in bedrock by young-looking geomorphic features.

Maumee Fault Rupture

The Maumee fault ruptured along a strike generally parallel to the Homestead Valley fault, transferring slip to the Emerson fault (Figures 2b and 3). Maximum right-lateral strike-slip displacement was up to 105 cm (Sieh and Lilje, 1994) (locality 24, Figure 3). Vertical displacement was 18 cm (down to the west), although down to the east vertical offset also occurred. Surface fault rupture along the fault generally occurred where previously zoned, although differences between the rupture traces and zoned traces occur in the vicinity of locality 25 (Figures 2b). This western trace, which was mapped by Morton and others but not recommended for zoning, ruptured in 1992.

The southern end of the Maumee fault may join with the Homestead Valley fault along a northeast trend. Rupture was mapped along the west side of a northeast-trending linear drainage, and had up to 34 cm of right-slip and 20 cm vertical displacement (down to the east).

Geomorphic Expression Maumee Fault

The Maumee fault generally is well-defined in bedrock by right-laterally deflected drainages, a broad linear sidehill trough, beheaded drainages, ponded alluvium, and sidehill benches (Figure 4b). The western trace mapped by Morton and others in the vicinity of locality 25 (Figure 4b) is delineated by a broad sidehill trough with associated right-laterally deflected drainages. Manson (1986b) extended the principal trace of the Maumee fault farther southeast than Morton and others, based on a southwest-facing scarp and ponded alluvium (locality 26, Figures 2b and 4b).

There is permissive geomorphic evidence suggesting that the Maumee fault joins the Homestead Valley fault in a complex manner along a south-southwest trend (Figure 4b). Fault rupture associated with the 1992 earthquake was reported along this south-southwestern trend along the west side of a broad linear drainage (locality 5, Figure 3).

GALWAY LAKE FAULT

Previous Mapping

The Galway Lake fault was zoned for special studies in 1988, based on surface fault rupture associated with the 1975 Galway Lake earthquake mapped by Hill and Beeby (1977) (Figures 2b and 2c).

Galway Lake Fault Rupture

The 1992 ruptures along the Galway Lake fault generally coincided with the 1975 faulting, although some differences in location exist (Figures 2b, 2c, and 3). Fault rupture was expressed as left-stepping en echelon fractures (Figure 3). Maximum right-lateral strike-slip displacement was 8.6 cm at the northern end of the rupture, diminishing to less than 1 cm near the southern end (Figure 3).

Geomorphic Expression Galway Lake Fault

The fault south of Galway Lake and north of the southern border of the Galway Lake quadrangle is moderately defined by degraded east-facing scarps in older alluvium and truncated older alluvium (Figures 2c and 4b). Adjacent to and north of the playa the fault is concealed by Holocene alluvium. The southern end of the fault is delineated by a relatively poorly defined, degraded east-facing scarp in older alluvium (locality 27, Figure 4b). Here the fault is mostly concealed by Holocene alluvium.

UPPER JOHNSON VALLEY FAULT

Previous Mapping

Traces of the Upper Johnson Valley fault (new name), mapped by Dibblee (1967) in the bedrock ridge just north and west of Means Lake, were evaluated by Manson (1986a) (Figures 2a and 4a) (traces mapped by Dibblee, 1967 and Manson, 1986a are not plotted on Figures 2a and 4a). Manson, who referred to the fault as "Fault C", did not recommend zoning the fault because it did not offset Pleistocene alluvium deposited across the southern end of the fault at locality 28 (Figures 2a and 4a).

Upper Johnson Valley Fault Rupture

Triggered slip associated with the Landers earthquake occurred along generally concealed traces of the Upper Johnson Valley fault north of the Melville Lake road (Hart and others, 1993) (locality 29, Figures 2a and 3). Cracks in two locations along Melville Lake road were reported by R. Hill, although the amount and continuity of displacement were not recorded (Figure 3). After the initial field work of July 1992, K. Lajoie noticed a distinct tonal lineament north of Melville Lake road on U-2 photography (USAF, 1992). No fractures were clearly observable on the photography, but a distinct tonal lineament similar in expression to other 1992 ruptures was mapped. The tonal lineament extended northwest for about 3.5 km and locally corresponds to geomorphic features suggestive of prior fault rupture (Figures 2a and 3). Lajoie (p.c., 1993), stated that the rupture zone was about 10 meters wide, discontinuous, and locally was delineated by a moletrack with up-to-the-east vertical displacement in the vicinity of Melville Lake road, based on a cursory field reconnaissance. Although no slip measurements were possible, Lajoie stated that the ruptures did not seem to have significant strike-slip displacement, suggesting that the feature is a monoclinal warp. Lajoie stated that the rupture did not extend south into the bedrock ridge, based on field observations in mid-July 1992.

Geomorphic Expression Upper Johnson Valley Fault

The Upper Johnson Valley fault is delineated by moderately defined geomorphic features in bedrock suggestive of right-lateral strike-slip displacement, such as right-laterally deflected drainages, linear drainages, saddles, benches, and right-laterally deflected ridges (e.g., localities 30, 31, and 32, Figure 4a). A right-laterally offset contact between Mesozoic quartz monzonite and quartz diorite gneiss mapped by Dibblee (1967) indicates about 300 meters of right slip (locality 33, Figure 4a). However, geomorphic evidence of Holocene displacement is weak. As reported by Manson (1986a), dissected older alluvium of Pleistocene age mapped by Dibblee (1967) conceals the fault at locality 28 (Figures 2a and 4a). Geomorphic expression of the fault north of the granitic bedrock hills is generally poorly defined by dissected, linear bedrock remnants (buried scarps?), a degraded linear bedrock ridge, and vague tonal lineaments in Holocene alluvium (e.g. localities 34 and 35, Figure 4a). However, there is moderate correlation between triggered slip associated with the Landers earthquake and the geomorphic expression of the Upper Johnson Valley fault (Figures 2a and 3).

JOHNSON VALLEY FAULT

Previous Mapping

Strands of the Johnson Valley fault in the Melville Lake-Emerson Lake study area were zoned for special studies in 1988 based mainly on the mapping of Manson (1986a), with some traces at the northwestern end mapped by Morton and others (1980) (Figure 2a). The 1992 fault rupture along the Johnson Valley fault did not extend as far north as the FER study area.

Geomorphic Expression Johnson Valley Fault

This part of the Johnson Valley fault zone is complex and generally bounds both sides of generally linear granitic bedrock hills (Figure 4a). The fault is delineated by abrupt bedrock scarps that face both east and west, right-laterally deflected drainages, linear drainages, beheaded drainages, and moderately to moderately well-defined tonal lineaments and vegetation contrasts and scarps in latest Pleistocene and Holocene alluvium (e.g. localities 36, 37, 38, and 39, Figure 4a).

WEST JOHNSON VALLEY FAULT

Previous Mapping

The previously unnamed West Johnson Valley fault, located west of the Johnson Valley fault, was zoned for special studies in 1988, based on mapping by Morton and others (1980), augmented with mapping by Manson (1986a) (Figure 2a). Manson referred to this fault as "Fault A".

Geomorphic Expression West Johnson Valley Fault

The West Johnson Valley fault is delineated by moderately to well-defined vegetation contrasts in Holocene alluvium and scarps and truncated sand dunes (Figure 4a). Traces mapped by Morton and others and Manson were generally verified by this writer (Figures 2a and 4a). It is possible to extend the fault to the south for a few hundred meters, but the geomorphic evidence, very vague tonal lineaments in Holocene alluvium, are not very compelling (Figure 4a).

INFERRED FAULT A

A previously unmapped northeast-trending lineament (inferred fault) is located along the northern side of Melville Lake (Figure 4a). This feature is delineated by moderately defined linear vegetation contrasts, scarps, and truncated and aligned sand dunes (Figure 4a). The sense of displacement is unknown, but is probably left-lateral strike slip, based on the linearity of the features and the northeast strike. This feature was not checked for fault rupture following the 1992 Landers earthquake.

POST EARTHQUAKE INVESTIGATIONS

Trench investigations along the Homestead Valley, Emerson, and Johnson Valley faults following the Landers earthquake were done by Hecker and others (1993), Rubin and Sieh (1993), Lindvall and Rockwell (1993), and Herzberg and Rockwell (1993).

Hecker and others (1993)

Several trenches were excavated along the Homestead Valley fault zone in the Melville Lake-Emerson Lake study area by Hecker and others (1993) (localities 40 and 41, Figures 4a and 4b). Additional trenches were excavated along the Emerson fault east of the Melville Lake-Emerson Lake study area. Evidence of three earthquakes prior to the 1992 event were reported at the playa site on the western edge of the Emerson Lake quadrangle (locality 41, Figure 4b). The penultimate event occurred 5.7-8.5 ka, based on AMS radiocarbon dates on detrital charcoal from playa silts. The next earlier event was reported to have occurred shortly before 12.5-14 ka. Apparent vertical displacement for the penultimate event of 35-40 cm is similar to the vertical component formed during the 1992 event, suggesting that the net slip during the penultimate event was similar to the 1992 event. Assuming that the penultimate event was similar in slip to the 1992 event, a late Pleistocene and Holocene right-lateral slip rate of 0.4-0.6mm/yr is indicated.

Rubin and Sieh (1993)

Trenches excavated across the northern Emerson fault (in a playa just north of the Melville Lake-Emerson Lake study area) produced evidence of two rupture events prior to the 1992 event. The penultimate event occurred about 9 ka, and the earlier event between 14.8 and 24 ka. The age for the penultimate event was inferred from the AMS radiocarbon age of detrital charcoal in playa sediments. The age of the older event was based on dating of two pedogenic carbonate horizons that bracket the displacement. The age of the penultimate event is similar to the age of the last event on the Homestead Valley fault reported by Hecker and others (1993). Apparent vertical offset in the penultimate event was similar to the 1992 event, indicating that net slip was similar. This yields a late Pleistocene-Holocene right-lateral slip rate of about 0.2mm/yr at the playa. A few kilometers to the northwest total slip in 1992 approached 6 meters, suggesting that the right-lateral slip rate for the northern Emerson fault may be as high as 0.7mm/yr.

Lindvall and Rockwell (1993) and Herzberg and Rockwell (1993)

Trenches excavated across the northern Johnson Valley fault near Melville Lake exposed evidence of three events (trenches not shown; exact location not known). The penultimate event occurred between 9.1 and 9.4 ka, similar to the ruptures reported by Hecker and others (1993) and Rubin and Sieh (1993). The penultimate rupture occurred in a broad zone up to 15 meters wide, with an associated scarp similar to the 1992 rupture. An earlier event occurred between 9.4 and 9.5 ka and is characterized by cracking and minor displacement with no scarp. Herzberg and Rockwell concluded that this older rupture is indicative of a smaller earthquake, perhaps suggestive of triggered slip.

SEISMICITY

Seismicity in the Melville Lake-Emerson Lake study area prior to the 1992 Landers earthquake was dominated by the 1979 Homestead Valley earthquake swarm. Hutton and others (1980) stated that only one event of magnitude 2.5 to 3.0 occurred in Homestead Valley during the period between 1 January 1970 and 14 March 1979. More than 3,000 events occurred in this region between 15 March and 30 June 1979.

Earthquake epicenters in the FER study area for the period June to December 1992 are shown in Figure 5b (Hauksson and others, 1992). The Joshua Tree earthquake sequence of April 1992 is located south of the Pinto Mountain fault.

CONCLUSIONS

The 28 June 1992 M_W 7.3 Landers earthquake produced significant surface fault rupture along previously zoned traces of the Homestead Valley, Emerson, and Maumee (new name) faults (Figures 2a, 2b, 3). In addition, significant fault rupture occurred along previously unmapped minor faults between the Homestead Valley and Emerson faults and along the previously un-zoned Upper Johnson Valley fault (Figures 2a, 2b, and 3). Surface fault rupture associated with the Landers earthquake requires revisions to the Melville Lake, Emerson Lake, and Galway Lake Special Studies Zones Maps (Figures 2a, 2b, 2c, and 3). Surface faulting associated with the 1992 earthquake is shown on Figure 3. Although every attempt was made to map the ruptures as completely as possible, it should be recognized that not all ruptures may be shown on Figure 3. This is due to incomplete coverage of the 1:6,000 scale aerial photographs, especially in the relatively broad stepover areas and distal ends of ruptures.

Geomorphic evidence of Holocene right-lateral strike-slip displacement along faults in the Melville Lake-Emerson Lake study area exists, but is often subdued (Figures 2c, 4a, and 4b). Although rates of Holocene deposition in areas of low relief may often be high, the relatively moderate geomorphic expression of these faults is also due to a long return period and low slip rate. This has been demonstrated by Hecker and others (1993), Rubin and Sieh (1993), and Herzberg and Rockwell (1993). Radiocarbon ages of deposits offset during the penultimate event on the Johnson Valley, Homestead Valley, and Emerson faults show that the faults last ruptured during early to mid-Holocene time, between 5 and 9 ka. Late Pleistocene and Holocene right-lateral slip rates from 0.2 to 0.7mm/yr characterize strands of the Homestead Valley, Emerson, and Johnson Valley faults.

HOMESTEAD VALLEY FAULT

The Homestead Valley fault ruptured along its entire length in the 1992 Landers earthquake (Figure 3). Maximum right-lateral strike-slip displacement of 330 cm was reported at locality 1 (Figure 3). The principal trace of the Homestead Valley fault that ruptured in 1992 had been zoned for special studies in 1988, based on mapping by Manson (1986a), but several significant areas of rupture occurred outside of the special studies zones (Figures 2a and 2b). These include a complex step in the fault zone at the southern end of the study area that formed a zone almost 1.2 km wide (locality 2, Figures 2b and 3), rupture along the east side of a linear ridge at locality 3 (Figures 2b and 3), and a broad, complex zone of faulting that transferred slip from the Homestead Valley fault to the Emerson fault (Figures 2a and 3). Geomorphic evidence of recent faulting in the area between the Homestead Valley and Emerson faults generally is weak and the pattern and complexity of fault rupture could not be verified on pre-earthquake aerial photos (Figures 3, 4a and 4b). Almost all of the 1992 ruptures that occurred between the Homestead Valley and Emerson faults occurred along previously unmapped faults.

EMERSON FAULT

Maximum right-lateral strike-slip displacement (about 600 cm) associated with the Landers earthquake occurred along the Emerson fault north of the Melville Lake-Emerson Lake study area. The 1992 displacement along the Emerson fault in the study area reached a maximum of about 152 cm along a branch fault located west of the principal trace of the Emerson fault (locality 18, Figure 3). The Emerson fault did not rupture in 1992 south of its intersection with the Maumee fault (Figure 3).

Traces of the Emerson fault south of the 1992 rupture were mapped by this writer, based on interpretation of USDA (1952 and 1953) aerial photographs (Figures 4a and 4b). Although mapping by this writer mostly corresponds to traces zoned for special studies in 1988, differences in detail exist at localities 20, 21, and 22 (Figures 2b and 4b). The larger scale USDA aerial photographs were not available to Manson (1986a) when the Mojave Desert region was originally done. Thus, the interpretations by this writer shown on Figures 2a, 2b 4a, and 4b are thought to be the most detailed and should be used as the basis for zoning revisions in the Emerson Lake quadrangle.

MAUMEE FAULT

The Maumee fault is a previously unnamed right-lateral strike-slip fault thought to be a branch of the Emerson fault (Figures 2b, 3, 4b). The fault was zoned for special studies in 1988, based on mapping by Morton and others (1980) and Manson (1986b) (Figure 2b). Maximum right-lateral strike-slip displacement of up to 105 cm and vertical displacement to 18 cm was reported along the Maumee fault (Sieh and Lilje, 1994) (locality 24, Figure 3). The 1992 fault rupture generally occurred along the previously zoned traces of the fault, although differences between the rupture traces and zoned traces occur at locality 25 (Figure 2b).

GALWAY LAKE FAULT

Most traces of the Galway Lake that ruptured in 1975 also ruptured in 1992. However, the 1992 rupture, which reached a maximum of 8.6 cm right-lateral, did not extend as far north as the 1975 ruptures (Figures 2c and 3).

UPPER JOHNSON VALLEY FAULT

Traces of the previously unnamed Upper Johnson Valley fault were evaluated by Manson (1986a) and not recommended for zoning. This decision was based on the lack of offset of a dissected Pleistocene alluvial unit (locality 28, Figure 4a) and the general lack of youthful fault-produced geomorphic features in bedrock. Traces of the Upper Johnson Valley fault had minor triggered slip caused by the Landers earthquake, based on observations by K. Lajoie (p.c. February 1994) and interpretation of U-2 aerial photographs (USAF, 1992) by this writer. Sense and amount of slip are not precisely known, but field observations by Lajoie suggest oblique slip with up-to-the-east vertical displacement and a component of right slip. The 1992 slip can be traced on aerial photographs for at least 3.5 km (Figure 3). The geomorphic expression of the fault is suggestive of minor Holocene right-slip displacement with a very low slip rate (Figure 4a).

JOHNSON VALLEY FAULT

Traces of the Johnson Valley fault in the Melville Lake-Emerson Lake study area did not rupture in 1992. Most traces of the previously zoned Johnson Valley fault were verified by this writer, but with hindsight provided by the Landers earthquake, additional traces may be Holocene active and should be zoned, based on the similarity of geomorphic expression and structural relationships of these traces with other faults that ruptured in 1992. Manson (1986a) had recognized some of these strands, but recommended against zoning, based on a lack of clear Holocene offset. Principal areas that should be added include: Tonal lineaments in Holocene alluvium (in the vicinity of locality 39, Figure 2a) that are located outside of the Special Studies Zones; a well-defined west-facing bedrock scarp along the west side of Hill 3289 (locality 42, Figure 2a); and minor cross faults in the bedrock ridges of Hills 3289 and 3601 (Figure 2a).

WEST JOHNSON VALLEY FAULT

The previously unnamed West Johnson Valley fault did not rupture in 1992. Zoned traces of the fault, based on mapping by Morton and others (1980) and Manson (1986a) require only minor revisions as depicted in Figure 2a.

INFERRED FAULT A

Inferred Fault, located on the northern side of Melville Lake, is delineated by linear tonal contrasts and offset and linearly aligned sand dunes (Figure 4a). This previously unmapped feature is probably a fault, based on the linearity of its features. No surface fault rupture associated with the 1992 Landers earthquake was reported or observed along Inferred Fault A.

RECOMMENDATIONS

Recommendations for establishing Earthquake Fault Zones are based on the criteria of "sufficiently active" and "well-defined" (Hart, 1992).

HOMESTEAD VALLEY, EMERSON, MAUMEE, AND GALWAY LAKE FAULTS

Revise the 1988 SSZ (EFZ) Maps of the Melville Lake, Emerson Lake, and Galway Lake 7.5-minute quadrangles to incorporate all surface fault ruptures associated with the 1992 Landers earthquake characterized by greater than 1 cm of lateral or vertical displacement and having continuity along a linear trend as depicted in Figures 2a-2c. Principal references cited should be Bryant (this report), Lajoie (1993), Sieh and Lilje (1994), Manson (1986a and 1986b), Hill and Beeby (1977),

UPPER JOHNSON VALLEY FAULT

Establish Earthquake Fault Zones to encompass traces of the Upper Johnson Valley fault that ruptured in 1992, and mapped by Bryant (this report) as shown in Figure 2a. Principal references cited should be Dibblee (1967) and Bryant (this report).

JOHNSON VALLEY FAULT

Revise the 1988 SSZ (EFZ) Map of the Melville Lake quadrangle to incorporate traces of the fault as shown in Figure 2a. Principal references cited should be Manson (1986a), Morton and others (1980), and Bryant (this report).

WEST JOHNSON VALLEY FAULT

Revise the 1988 SSZ (EFZ) Map of the Melville Lake quadrangle to incorporate traces of the fault as shown in Figure 2a. Principal references cited should be Manson (1986a), Morton and others (1980), and Bryant (this report).

INFERRED FAULT A

Establish Earthquake Fault Zones to encompass traces of Inferred Fault A as shown in Figure 2. Principal reference cited should be Bryant (this report).

Report reviewed and approved. Earl W. Hart Sen. Geol. CEG 935 7/20/94

William A. Bryant

William A. Bryant
Associate Geologist
CEG# 1554
July 18, 1994

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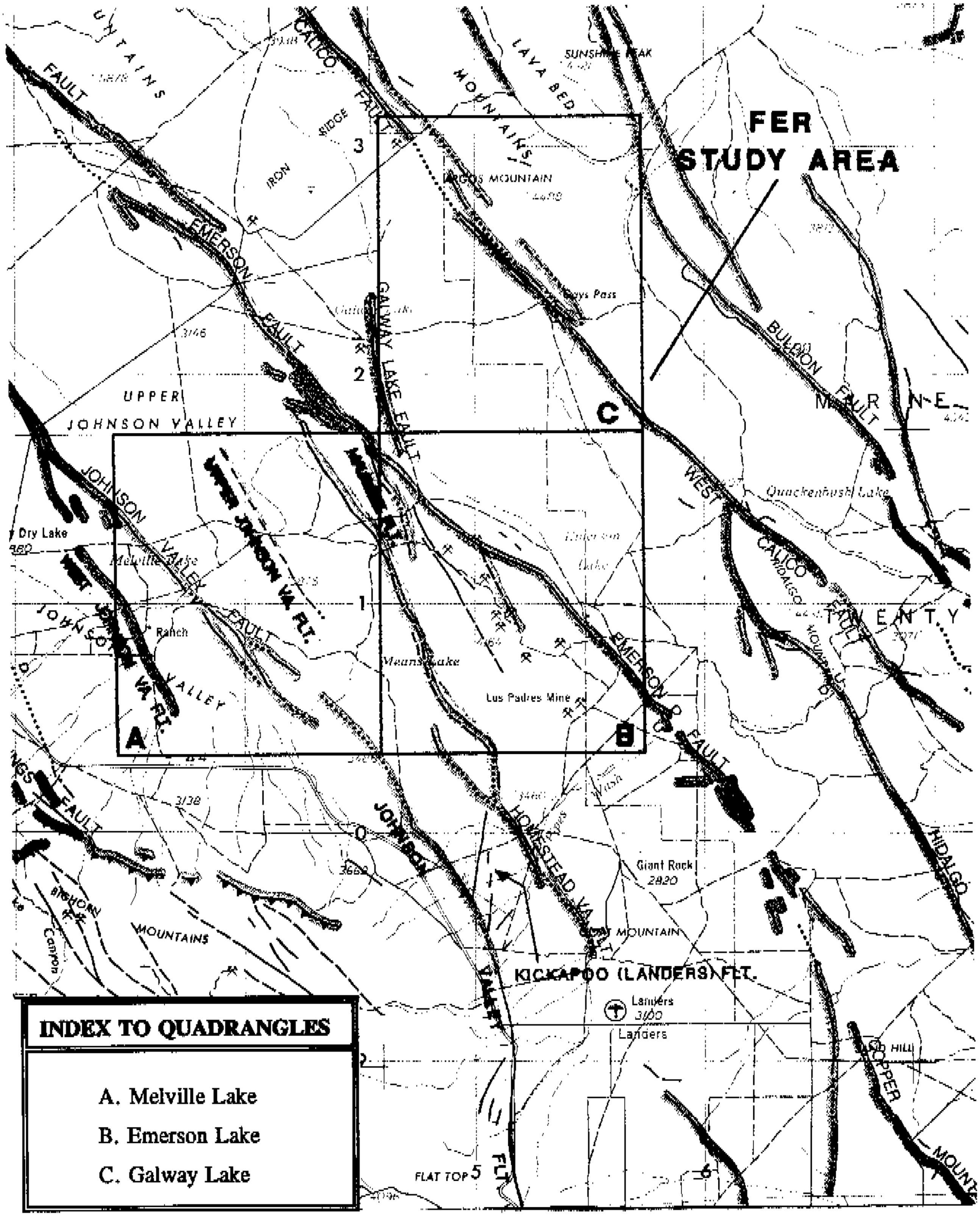

Figure 1 (to FER-239). Location of faults in the Melville Lake-Emerson Lake study area. Fault rupture associated with the 28 June 1992 Landers earthquake is highlighted in red. Base map from Bortugno and Spittler (1986), scale 1:250,000.

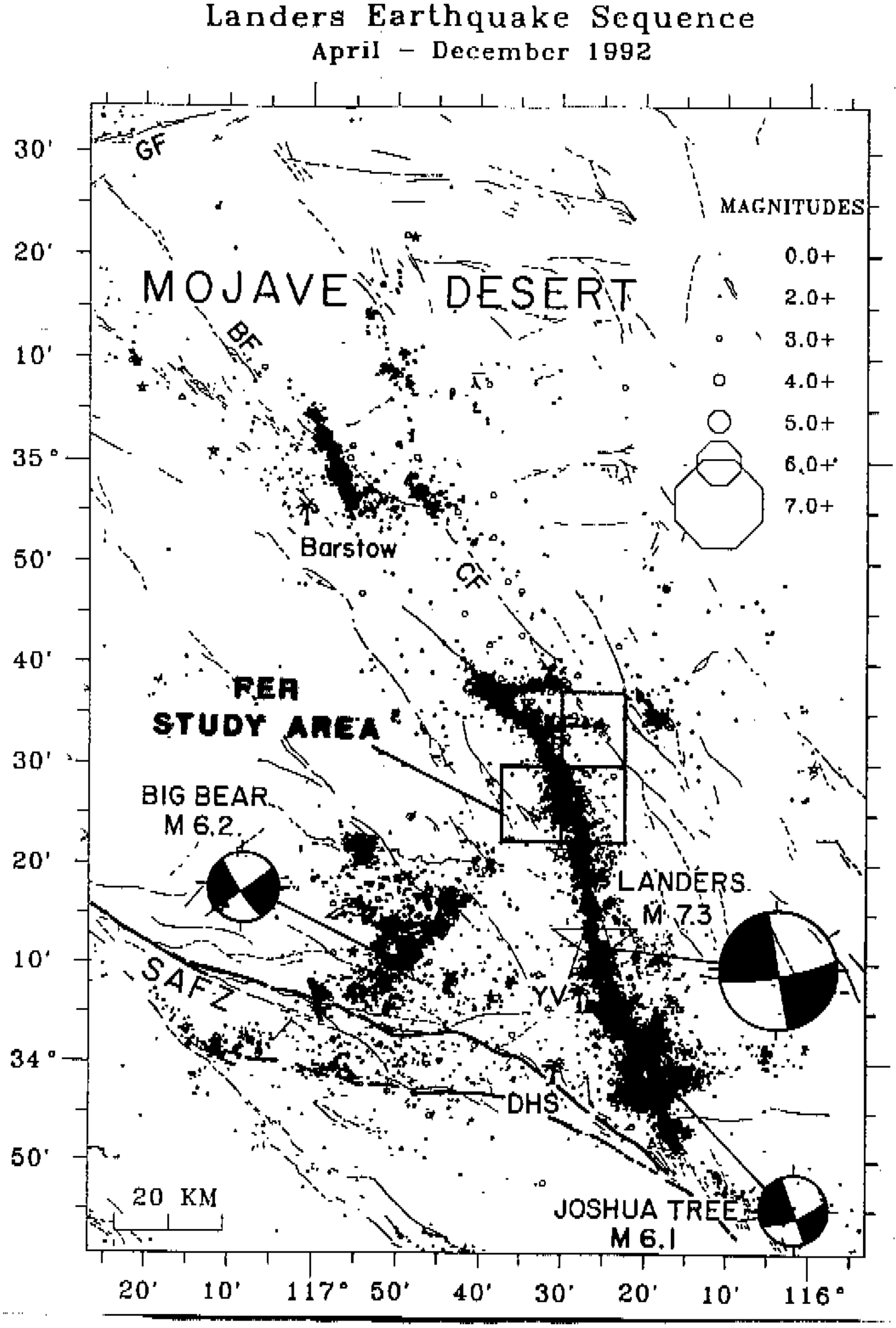

Figure 5a (to FER-239). Seismicity in the Melville Lake-Emerson Lake study area for the period April to December 1992. Lower hemisphere focal mechanisms (compressional quadrant shaded) of the three main earthquakes in the Landers area are shown. BF, Blackwater fault; CF, Calico fault; YV, Yucca Valley; GF, Garlock fault; SAFZ, San Andreas fault zone; DHS, Desert Hot Springs. *Modified from Hauksson and others, 1993.*

Landers Earthquake Sequence
June – December 1992

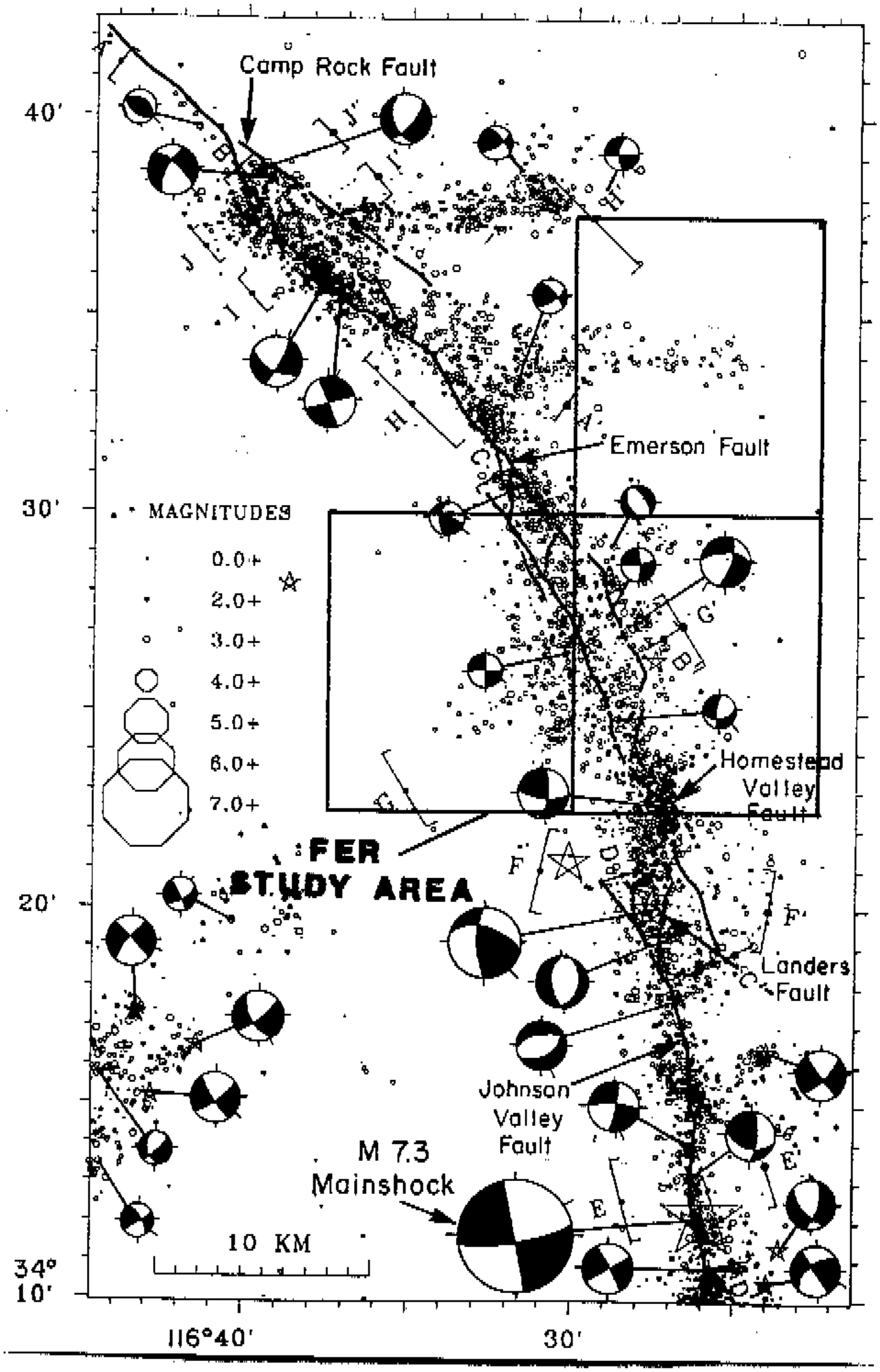

Figure 5b (to FER-239). Main shock and aftershocks of the 28 June 1992 Landers earthquake, 28 June to 31 December, 1992. Earthquakes M ≥ 4.0 are shown by stars. Modified from Hauksson and others, 1993.